

## **Towards Sawdust Products Ecosystem? Three Utilization Process Cases From Finland**

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## **TOWARDS SAWDUST PRODUCTS ECOSYSTEM?**

### **THREE SAWDUST UTILIZATION PROCESS CASES FROM FINLAND.**

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#### **Abstract**

There is a huge demand to utilize renewal side flows of different production processes to substitute existing fossil-based products or to develop and produce totally new products to the market. One underutilized side product is sawdust. Sawdust is very interesting as a raw material because of its structure, chemical components and availability globally. The objective of this paper is to analyze huge processing possibilities of sawdust. Three process concepts, which are in different development phases, are used as examples to illustrate the large variation of products.

Production processes and novel products are challenging existing value chains in this business, which traditionally has been business interactions between mechanical wood processing and energy, because sawdust has mostly been seen as solid, renewal fuel. The value capture from sawdust enables novel value chains to many businesses like chemicals, food ingredients and cosmetics. This paper discusses about the transition from cluster to cluster business into sawdust ecosystem. The cases are evaluated based on current literature, bibliographic, patent searches and technology readiness level. The findings show, that sawdust processing business already fulfill the criteria for ecosystem.

**Keywords:** Sawdust, value upgrading, industrial symbiosis, ecosystem, circular economy, value chain

#### **1. Introduction**

The main products of forest industry are pulp and paper with sawn goods. Timber is the main product of sawmills. The main utilization areas of timber are in construction and furniture products. When round wood is converted to rectangular logs by sawing, residuals are produced. Sawdust is a major side-product of the commercial mechanical wood processing. Sawmilling can produce close to 30 % sawdust of final timber production, but in modern sawmills the figure is close to 20% (Hassan et al., 2019).

Sawdust can be defined as fragments and small pieces of wood after the sawing process. During the sawing tree cells or group of cells forming solid wood are destroyed. The destruction of cell group causes the formation of chip fragments while the shattering of actual cells form the dust. The sawdust particle size distribution is typically between 0,2 to 2,0 mm (Kilpeläinen et al., 2014).

Sawdust has traditionally been used as an untreated fuel in boilers or converted to products like pellets and briquettes. It is frequently burned to make heat and electricity in various industries and plants producing electricity and heat. The moisture content of undried sawdust is approximately 50-55 % and the heat value dry sawdust produces when burnt is 18.9-19.2 MJ/kg which is about 5.3 kWh/kg (Alakangas et al., 2016). Sawdust can also be used as feedstock of pulp mill, but the sawing reduces the original fiber length to level less than 2 mm which can reduce the pulp strength when softwood is used. Despite of that, sawdust is excellent raw pulp raw material for special purposes like demanding packaging products like in Kotka Mills Ltd, Finland.

Where do new wood-based products come? The increase of added value from existing feedstock flow can be achieved by developing alternative products (product innovation) or production process (process innovation) or moving downstream in existing value chain (organizational innovation), Gupta et al. (2016). This paper introduces and discusses three novel production processes enabling several products which are neither new or substitutes to existing products.

The most interesting increasing wood-based product markets are expected to be construction, textiles, chemicals, biofuels added by some niche markets like cosmetics, food additives and pharmaceuticals (Näyhä et al., 2014). This paper introduces products to be used for chemicals, biofuels, cosmetics and pharmaceuticals.

The objective of this paper is through three production cases all using sawdust as feedstock illustrate the huge ongoing expand from classic cluster to cluster (forest-energy) alliance to ecosystem dealing with several businesses where the products are end products or intermediate products. This paper discusses also of barriers which start-up companies or already existing SMEs should pass before they with their novel products are ready compete on the markets.

Technological and wood characteristics details are represented in this paper slightly, only on the level which helps readers and researchers to understand the differences of chosen process cases. Research question of the paper is "How the ongoing novel sawdust utilization processes and products fit to ecosystem characteristics?"

## **2. Literature**

This chapter introduces recent literature related to business transition from clusters to ecosystems (Chapter 2.1) and introduction to sawdust and sawdust processing options (Chapter 2.2).

### **2.1 Transition from clusters to ecosystems**

The original idea of the industrial cluster by Michael Porter was competition between the included companies (Porter, 1998). The competition between companies in a given environment was supposed to create competitive advantage within the cluster in a country where the cluster companies were located in close vicinity. It is recognized that the traditional (closed) cluster-based policy does not provide enough new potential growth sectors to the economy (Hausman and Rodrik, 2006; Hämmäläinen, 2010). The shortages of current policies have been identified in enhancing growth companies particularly in the areas remaining between existing strong clusters and renewal of existing clusters. Many innovation policy instruments that might mitigate problems are used in trying to enhance the performance of the innovation system. The cluster driven models have changed into ecosystem during last decades which is better term to describe multilevel connections between clusters in dynamic operation environment.

The ecosystem is characterized by an independence of cooperating and competing (but complementary) network of partners, a structured community, and it plays a critical role in determining value co-creation and co-capture (Moore, 1993). Teece (2007) has another definition to ecosystem. He sees ecosystem as environmental context not of industry but a business community of organizations, institutions and individuals who determine institutional logic and formation of collective value creation.

Industrial symbiosis is a subset of industrial ecology. It describes how a network of diverse organizations can foster eco-innovation and long-term culture change, create and share mutually profitable transactions—and improve business and technical processes (Lombardini and Laybourn, 2012).

Industrial Symbiosis (IS) is an innovative approach to create industrial networks (Isenmann and Chernykh, 2009) for economic, environmental and social benefits. IS brings together companies from all business sectors through material trading and sharing assets to add value, reduce costs and benefit the environment (Lehtoranta et al., 2011). Developing IS networks is a knowledge-intensive practice, where information is necessary to discover potential IS connections between flows of materials, waste and/or other resources related to industrial facilities.

In ongoing transition phase of forest industry renewal there are lots of opportunities to start-up and small and medium size enterprises (SMEs). The production of value-added niche products from existing side flows is not as capital intensive as traditional production, which has been normally based on “scale efficiency paradigm” (Antikainen et al., 2017).

The factors affecting to the entry of SMEs into bio-based industry has been studied by Jernström et al. (2017) and model of small actors’ engagement in bioenergy business by Kokkonen and Ojanen (2018). Market potential is a function of various demand side (market pull) and supply side (technology push) factors (Lee and Geum, 2017). This is a challenge with cases when existing, often fossil based products, are substituted by renewal products. Is there space on the market and if there is, how much more the consumers are ready to pay for “greener” alternative? This is a challenge to cost efficiency of new products and their production processes.

## 2.2 Sawdust and sawdust processing options

The overview of wood raw material flow in sawmills is shown in Figure 1. Sawdust is also a side product of plywood process, but the amount is much smaller compared to sawmill flows.

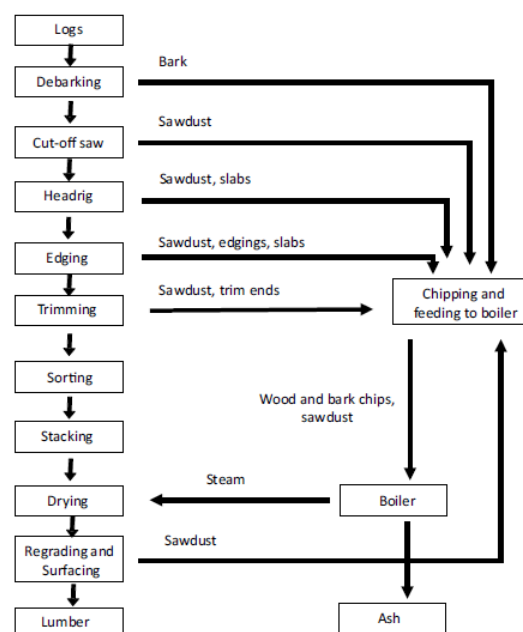


Figure 1. Overview of wood raw material flow in sawmills. Adopted from Hassan et al., 2019.

Figure 1 illustrates traditional way to utilize sawdust almost only to steam generation used to lumber drying. This is still relevant format especially in SME size sawmills in stand alone locations without close geographical connection to other sawdust utilization paths. In many cases the wood residuals with bigger particle size distribution than sawdust (e.g. chips) are used as feed flow to pulp mills. In Finland the most important industrial wood species are pine (*Pinus sylvestris*), spruce (*Picea abies*) and birch (*Betula pendula*, *Betula pubescens*).

The current mass production of sawdust-based products is normally linked to energy production via direct fuel use in boilers, conversion to pellets or briquettes or conversion to motor fuel components like ethanol (Nabuurs et al., 2014). The situation reflects to sawmill site location vs. potential refining units (Karvonen et al., 2015). To stand alone sawmills the logistics costs for sawdust transportation might be much higher compared to integrated production sites where further utilization steps are already existing. Ethanol conversion offers also path to other products (e.g. lignin, furfural, wood syrup) which can be used as intermediate product towards more valuable products. This kind of arrangement of course increases the total economical potential in raw material utilization. Figure 2 illustrates an example on wood-based platform chemicals and biofuel value chains when utilizing enzymatic hydrolysis.

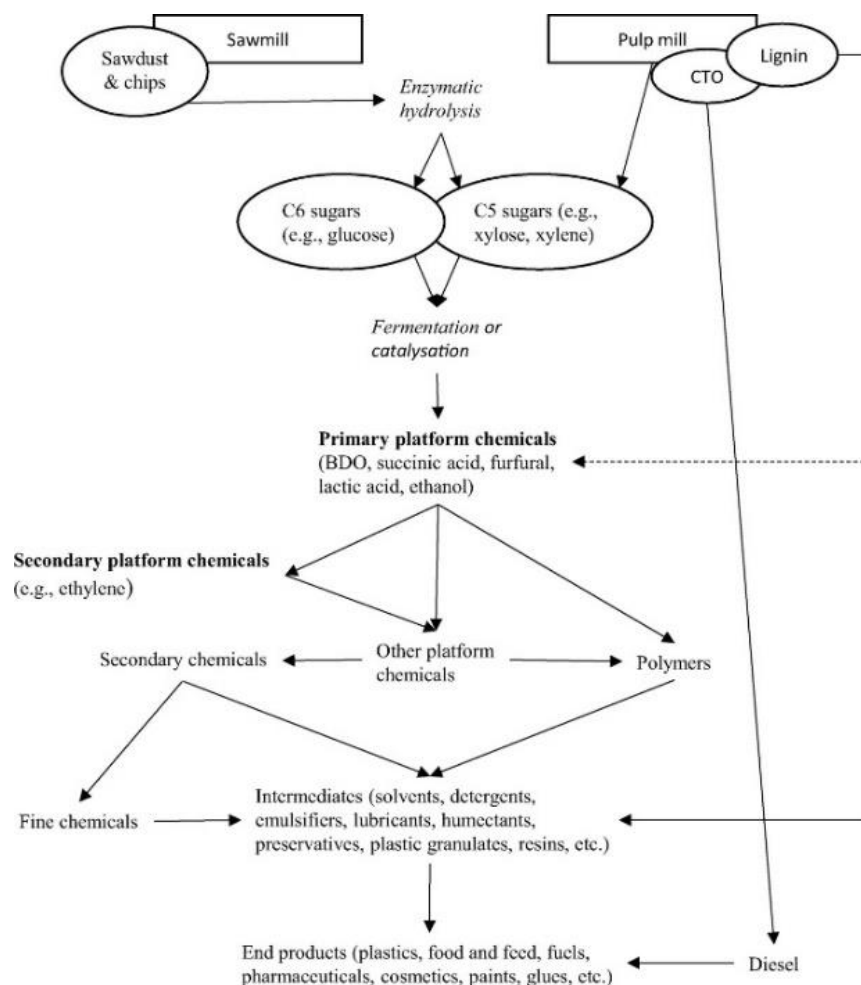


Figure 2. Platform chemicals and biofuel value chains when utilizing enzymatic hydrolysis of wood (dashed line refers to processes that could be relevant past 2030). Adopted from Hurmekoski, et al. 2018.

Figure 2 shows the huge potential of value capture on the way to primary platform chemicals (e.g. ethanol and furfural) via intermediates to end products like pharmaceuticals, herbal extracts, food ingredients and cosmetics.

### 3. Methods and data

#### 3.1 Methods

The main research method used in this paper is descriptive research. This type of research describes what exists and may help to uncover new facts and meaning. The purpose of descriptive research is to observe, describe and document aspects of a situation as it naturally occurs (Borg and Gall, 1989). Descriptive research projects are designed to provide systematic information about the researched phenomenon. The researcher does not usually begin with a hypothesis but is likely to develop one after collecting data. The analysis and synthesis of the data provide the test of the hypothesis. It does not answer questions about how/when/why the characteristics occurred. Rather it addresses the "what" question. There are three main types of descriptive methods: observational methods, case-study methods and survey methods (Hale, 2011).

The case study plays important role in this study. Case study principles has studied by Benbasat et al. (1987), Simon et al. (1996), Darke et al. (1998) and Yin (2009). With small data like in this case, the generalization of case study research results has not committed. The cases illustrate only examples of connections between traditional branch of industries.

Technology readiness level (TRL) scale is used in evaluation of cases. It has been used in technological evaluation in conversion of sugars to biofuels and biochemicals by Taylor et al., 2015. It is relatively simple way to define the status of path from idea to market. The principle is shown in Figure 4.

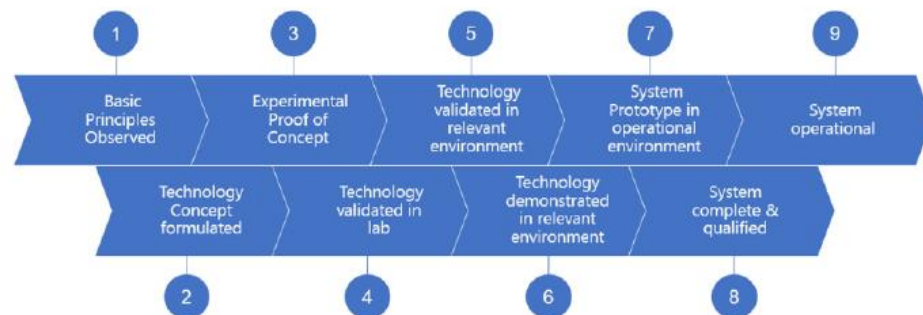


Figure 4. Technology readiness level. Adopted from EC, 2017.

#### 3.2 Data

The literature search used Scopus database, which is one of largest multidisciplinary abstract and citation databases of peer-reviewed scientific literature. The keywords for literature search were supposed to cover the state-of-the-art in general (sawdust) and it's fragments related to cases used in this paper.

The patent search used commercial Patseer Pro database. The database includes over 89 million full text records of 67 countries and over 129 million biblio-records covering over 106 countries. The Patseer Pro database was chosen because of its powerful search tools and ability to focus search on specific part of patent text. The search was done with same keywords than search in Scopus database.

Table 1. Results (hits) of Scopus database study (29.10.2019) and patent search (14.02.2020) by Patseer Pro database.

	AND	Scopus	Scopus hit share, %	Patent	Patent hit share, %
<b>Sawdust</b>		9796	100	137172	100
	Product	1970	20,1	17532	12,8
	Energy	1632	16,7	4724	3,4
	Adsorbent	710	7,2	882	0,6
	Utilization	574	5,9	1742	1,3
	Food	466	4,8	4508	3,3
	Pellet	432	4,4	3287	2,4
	Extract	353	3,6	2346	1,7
	Ethanol	218	2,2	742	0,5
	Briquet	95	1,0	1750	1,3
	Coatings	94	1,0	2207	1,6
	Absorbent	44	0,4	2000	1,5
	Pharmaceutical	43	0,4	153	0,1
	Paint	26	0,2	692	0,5
	Cosmetics	18	0,2	90	0,1

Table 1 shows huge variation in number of hits between Scopus and Patseer Pro databases even same search words were used. In this context the novelty limit is set to 2 % of hits. Below that level Scopus found terms sawdust and briquet, coatings, absorbent, pharmaceutical, paint and cosmetics. The results of Patseer Pro search the same criteria were the same added by sawdust and adsorbent, extract and ethanol. Both scientific data search results and patent data analysis show similar identification of novelty and the results emphasize the processes and products of chosen cases.

### 3.3 Case introduction

All three cases use sawdust as feedstock. Cases represent different development phases on technology readiness level. The first case, St1 is an example of a multiproduct biorefinery process in industrial scale. Second, Montisera's process, is an example of maximizing the added value. PURASU concept is still in development but the preliminary results are interesting. The total product bidding covers many uses and markets (Hurmekoski, et al. 2018: Näyhä et al., 2014). Technological papers relevant to cases: bioethanol (Lin and Tanaka, 2006: Sánchez and Cordona, 2008), hot water extraction (Krogell et al., 2013) and biomass as fuel (Saidur et al., 2011).

**St1 Ltd** has a demo scale plant in Kajaani, Finland for bioethanol production, established in 2017. This demonstration unit uses annually 80 000 tons of pine and spruce sawdust at nameplate capacity. The



products are 10 million liters of bioethanol, 30 000 tons lignin, 10 000 tons wood syrup, 500 tons furfural and 150 tons of turpentine. Side products are biogas and carbon dioxide (CO<sub>2</sub>) from fermentation process phase. The process combination is called Cellunolix®-process. Actually, this process is a biorefinery because raw material is converted to many products in site. Operative staff in plant is 15 persons and the process is operating 24/7.

St1 Oy is already a remarkable operator in motor fuel business and the bioethanol fraction can be used in their own distribution chain. Use of a side product from existing wood processing plant saves cultivation areas to food production. Wood syrup is an alternative solution as fertilizer by substituting fossil-based nitrogen and it is increasing organic compounds in soil (carbon storage). Furfural and turpentine are examples of platform chemicals, see Figure 2.

**Montisera Ltd** is an innovative Finnish Turku-based drug discovery company. Montisera has patented ligneous wood derived extract for health benefiting purposes (Montisera, 2015). The most potential product, Qusitol®, is a galactoglukomannan-rich hot water extract from Norway spruce sawdust (*Picea abies*). Montisera has shown in preclinical test Qusitol® to act as a therapeutic agent for preventing and treating lower urinary tract symptoms (Konkol et al. 2017). Another product, Sprucegum™, is an example of a non-conventional but potential ingredient for food applications (Mikkonen et al., 2016).

Even the main product yield from sawdust is relatively small, the unit price of this kind of products is at least up to hundreds of euros per kilo. The way to the market is challenging and long to pharmaceuticals but the expected market potential is huge.

**PURASU Concept** is developed by LUT University in Lappeenranta, Finland. The process uses hot water extraction and the focus is in hemicellulose separation. Raw material to this process is spruce sawdust. The planned product is intermediate which can be tailored according to customer's needs. The potential customers are in cosmetics, food and coating businesses. The second main fraction consists of oligo and monosaccharides, which can be used for biofuel and food production.

The extracted sawdust is used in the PURASU process to purify the wood extract (Kallioinen and Mänttari 2019a, 2019b). This enables the fractionation of wood extract and recovery of hemicellulose fractions with membrane filtration (4 kDa membrane) with a reasonable filtration capacity. Combining of the use of the extracted saw dust and membrane filtration, GGM fractions of which purity is 90% have been recovered (yield 55%). The residual fraction, extracted sawdust, can be used for pellets, particle board material, filler to composite materials and adsorbent for water purification.

According to the preliminary tests the use of the extracted sawdust in composites improved the moisture resistance. The use of the extracted sawdust in water treatment applications seems also to be an interesting possibility. For instance, the extracted sawdust has been at LUT university found out

to have significantly better capability to remove oil from oily wastewater compared to fresh sawdust. Sawdust is also a feasible filter material for removal of phosphorus and microplastics from water and it can be utilized in removal of drug residues as well.

Table 2. Case characteristics comparison.

	<b>St1</b>	<b>Montisera</b>	<b>PURASU</b>
Development phase	Industrial	Pilot scale	Lab scale
Novelty / Scopus	+	+++	++
Novelty / Patents	+	++	++
Main product (MP)	Ethanol	Qusitol®, the galactoglucomannan-rich hot water extract	Glucomannan
Side products	Lignin, wood syrup, furfural, turpentine, biogas, liquid CO <sub>2</sub>	Hemicellulose-free spruce sawdust	Adsorbent, pellets
TRL	9	6	4

Novelty scale; + existing, ++ relatively new, +++ high novelty

#### 4. Discussion

The case processes and their products used this article are relatively new based on the results by scientific literature and patent searches (Table 1). The utilization of case products fit well to the frame from recent literature (Näyhä et al., 2014; Hurmekoski et al., 2018). The cases used are using only two wood species pine and spruce which are main raw materials to sawmills in Finland. Despite this limitation pine and spruce enable to product wide range of different products, both intermediates and end products.

The cases used in this paper give a slight idea of wide range product opportunities which sawdust as a raw material offers, Table 2. The St1 case introduces a holistic solution to sawdust utilization with multiproduct production concept. Beside the main product, bioethanol, several platform chemicals are produced (Hurmekoski et al., 2018). PURASU production concept is focused to one main product, glucomannan, but as a side product it offers adsorbents and pellets as well. The Montisera product portfolio is clearly based on galactoglucomannan-rich hemicellulose extracts. The multi-functionality of this extract suggests that it is having health benefiting properties, and it could replace other emulsion stabilizers. The expected market value of these products makes the case very interesting.

In all cases the total commercial use of sawdust is round 100 %. In PURASU and Montisera cases the sawdust is “loaned” from the traditional process for value creation and the residuals can be returned to circulation. St1 and PURASU processes are easier to finetune to use different wood species, not only pine and spruce. The Montisera process is more challenging, but on other hand it is not going to be a classic mass production.

The data used in this paper show clearly that in these cases somebody's waste is someone's raw material according to the industrial symbiosis idea (Lehtoranta et al., 2011), which leads to overall material efficiency and creates new business possibilities to whole ecosystem.

## **5. Conclusions**

Contribution of this study is to introduce novel utilization ways to sawdust. Three different cases were used as examples to illustrate the wide range of possibilities in sawdust utilization. With these new processes and products the forerunner companies cross traditional cluster borders according to the standard industrial classification where traditionally alliance was between forests and energy industries. This ongoing change offers excellent platform to new ecosystems (Moore, 1993; Teece, 2007).

The novelty related process concepts used in this study were checked by academic literature study (Scopus) and more company-oriented way by Patseer Pro patent database. From both sources the number of search hits were evaluated by reverse hit amount. This search was added by technology readiness level (EC, 2017) evaluation. The three cases are all in different readiness level which is interesting.

The cases introduced in this paper fit very well to ecosystem ideology. With their products the companies utilizing sawdust overstep the traditional cluster borders with novel value chains. This needs wide understanding of different businesses and many strategic choices (e.g. to manufacture intermediate with high volume or customer tailored special fractions with lower volume). The cases used in this paper illustrate only one approach to current development.

The focus of this study was to identify the business change in sawdust utilization, not the causal relations to the business parameters including capital and operational costs. In the next research step the quantitative research is needed to proof the business advantages based on this kind of openings.

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